national accelerator laboratory

Proposal 0008

December 6, 1974

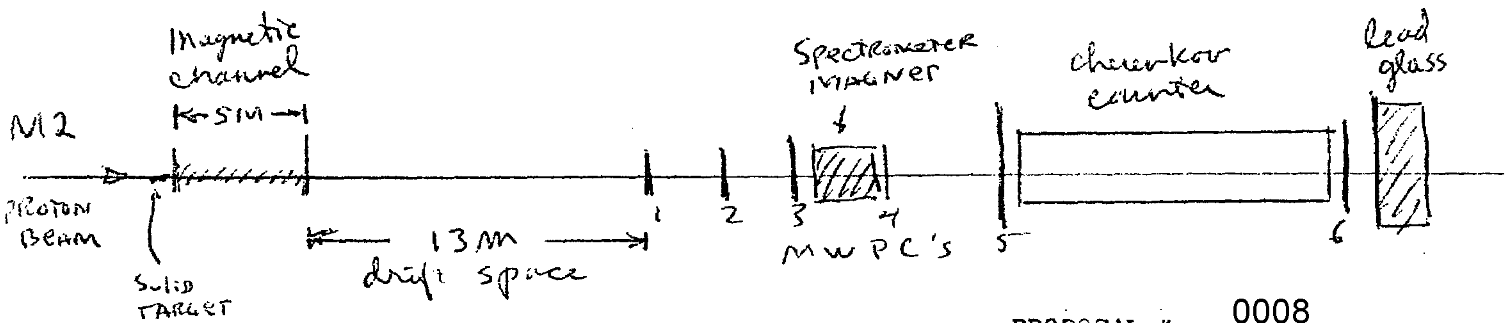
To: T. Groves — Director's Office

From: L. Pondrom — Experiment 8

Subject: New Particle Searches Now Being Performed and to be Performed in the Immediate Future by Experiment 8

I. Introductory Remarks

Experiment 8 has a working multiwire proportional chamber charged particle spectrometer and lead glass array for γ-ray detector which can record 250 events/spill with the present computer core. The spectrometer is placed symmetrically about the 300 GeV proton beam in the M2 line. Normally, a target is placed in the M2 line 18 meters upstream of the spectrometer, and a 5-meter long magnetic channel is used to sweep charged particles out of the neutral beam. A gas Cerenkov counter which can distinguish baryons from mesons at momenta below 200 GeV/c is installed downstream of the spectrometer analyzing magnet which has $\int Bdl$ = 1 GeV/c, and an aperture of 60 cm horizontally by 20 cm vertically.



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II. Production by 300 GeV Protons of New Long-Lived ($\tau > 10^{-11}$ sec) Neutral Particles Which Decay in the Neutral Beam

The Experiment 8 spectrometer detects two charged particles and any γ rays in the hyperon beam. The transverse momentum of the charged particles is restricted to values $p_\perp \leq 229$ MeV/c ($K^0 \rightarrow \pi e \nu$) for all known decay modes of known long-lived neutrals. The primary signature of a new heavy neutral particle would be a charged decay product with $p_\perp > 229$ MeV/c. Candidates satisfying this criterion are now being studied.

III. Production by 300 GeV Protons of New Short-Lived ($\tau < 10^{-13}$ sec) States Which Decay into Strange Particles at the Production Target

Inclusive production spectra for Λ, $\bar{\Lambda}$, K, Ξ, $\bar{\Xi}$ are being measured as a function of secondary momentum for production angles between 0 and 10 millirad. New states which decay into strange particles near the point of production might be detectable by such inclusive measurements. The $\bar{\Lambda}$ channel is particularly sensitive to such decays because it is difficult for an incident proton to make a $\bar{\Lambda}$ directly. For $\bar{\Lambda}$ production, the $p_\perp$ distribution out to $p_\perp = 1.5$ GeV/c, the longitudinal polarization, and the s dependence of the cross section can be measured. If a new state gives $\bar{\Lambda}$'s with a maximum value of $p_\perp$ within the observable range, then an enhancement can be expected in the $p_\perp$ distribution. The excitation function might show a threshold effect. A weak decay might result in a longitudinal polarization.

Data are now being analyzed on Λ's and $\bar{\Lambda}$'s at 0 millirad from carbon and copper targets.

A further investigation of possible decays as the source of the $\bar{\Lambda}$'s could be done by measuring a muon from the production target in coincidence with the hyperon. This intriguing possibility would require only the addition of muon telescopes to the present apparatus. Such telescopes are actually in place now as beam monitors.

IV. Production by Λ's or Neutrons in the Neutral Beam of New Short-Lived States from Complex Nuclear Targets

Carbon and copper targets will be inserted in the Λ^0 beam downstream of the hyperon sweeping magnet to search for short-lived states which decay into two charged particles detected by the spectrometer. These measurements were originally planned to measure the production of Σ^o by Λ^o, but they will include a search for new states as well.

At an intensity of 10^8 protons/pulse in the M2 beam line the neutral beam would consist of 10^3 Λ's and 3×10^4 n's. This proton flux is easily obtained in the M2 line. Using a target of 1/10 of an interaction length of carbon (4 cm), one new state produced by Λ's every ten pulses would correspond to a production level of $\tilde{}300$ μbar n. The efficiency of the spectrometer is quite good for detecting such states which are produced near the forward direction and decay with transverse momenta less than 2 GeV/c. Detection at a $\tilde{}30$ μbar n production cross section for Λ's or 1 μbar n for neutrons, seems conservative.

The flux of nucleons could be increased by $\tilde{}10^3$ by using the diffracted proton beam, steered through the collimator hole with the sweeping magnet off. This has already been done for alignment purposes. About 90% of the beam can be transported cleanly. The central region of the MWPC's would be deadened to prevent beam loading, but the sensitivity to high $p_\perp$ decays would not be adversely effected.

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NAL PROPOSAL No. 8

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Experiments in a Neutral Hyperon Beam

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Experiments in a Neutral Hyperon Beam

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ABSTRACT

We propose a survey experiment for a neutral hyperon beam, to measure production of Λ°, $\bar{\Lambda}^\circ$, Ξ°, $\bar{\Xi}^\circ$, $K_1{}^\circ$ - $K_2{}^\circ$ near zero mrad. by 200 GeV protons on complex nuclei. The detector will be sensitive to polarization of the hyperons. The same apparatus will then be used to search for $\Xi^\circ \rightarrow p\pi^-$ and to measure Λ° and $\bar{\Lambda}^\circ$ total and diffractive elastic cross sections in hydrogen.

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I. Neutral Hyperon Beam Survey

It has been known for some time that a practical neutral hyperon beam could be built at the National Accelerator Laboratory. Many features of this beam were considered in some detail during the 1969 summer study.[1] A charged particle spectrometer is described in this proposal which would be suitable for measurement of the relative fluxes in the neutral beam and for some early simple experiments. The experiments considered in detail are a search for the $\Delta S=2$ weak transition $\Xi^\circ \to p\pi^-$ and a study of Λ° cross sections in hydrogen in the 60 GeV - 130 GeV energy range. The apparatus required for these experiments is well within the limits of existing technology, and can be constructed by June, 1971. It is assumed that the short lived neutral beam will share a common facility with the short lived negative beam, and that the experimenters will be responsible for the compatibility. A high degree of collaboration between the laboratory and the neutral and negative beam groups is necessary to insure success of the program and to place minimum demands on the accelerator.

Production of Λ° hyperons by 200 GeV protons in hydrogen has been calculated by Walker[2] using the formulas of Hagedorn and Ranft. Production of hyperons in complex nuclei has been considered by Margolis and Pilkuhn.[3] Λ° hyperon production is predicted to reach approximately $3\Lambda^\circ$ per sterad per GeV/c interacting proton at 0 mrad and 120 GeV/c. Since the decay length for 120 GeV/c Λ° hyperons is 7.8 meters, the distance between the production target and the experimental area must be kept short, the order of 10 meters.

The main problem in the design of the short lived beam is the matching of this requirement to the shielding necessary for the operation of electronic detectors. Ten meters of iron would furnish a satisfactory hadronic shield, and the muons could be bent away magnetically, giving a muon free corridor for the apparatus. A curved channel could be cut in the shield to accommodate a negative hyperon beam. A 200 GeV proton beam in the intensity range 10^8 - 10^{10}, suitable for production of useful hyperon fluxes, has been discussed for Experimental Area Two by J. Walker, R. Stefanski, and A. Roberts.[4] Figure 1 shows a proposed layout from the proton target to the experimental decay region.

Estimates of the expected neutral particle yields based on Walker's calculations are shown in Table I. These numbers indicate that a beam survey could be performed with as few as 10^8 interacting protons/pulse. Figure 2 shows the apparatus for the beam survey. The basic idea is to measure the invariant mass of two oppositely charged particles from two body decays of neutrals. The design mass resolution of the spectrometer will be ±1%. The spectrometer magnet pole face should be about 30" wide with an 8" gap and a BL of 1800 kg-inches. Magnets with these characteristics are not uncommon at presently operating accelerators. For example an Argonne Labs BM-109 (24-8-72) could be used. The experimenters will be responsible for obtaining the magnet.

Great care must be taken in the construction of the spectrometer to keep the amount of material presented to the neutron beam to a minimum, and to keep the sensitivity of the apparatus to charged particle background as low as possible. No scintillators will be used in front of the magnet - the trigger will employ three "Charpak" counters. The largest of these will be about 30 cm x 30 cm. Each counter will be 2.5 mg/cm^2 thick, presenting about 4×10^{-5} of a neutron interaction length, or about 10^4 neutron counts/pulse in the third counter at full beam intensity. This should be a manageable counting rate. The large chambers behind the magnet will not be sensitive in the neutral beam region. The muon free "corridor" will cover all counters provided the spectrometer magnetic field and the magnetic field in the hadron shield are normal to each other.

Instantaneous data collection rates of the order of 500 per second during the beam spill will be buffer stored, and analyzed between accelerator pulses. When surveying the Λ° and K_S° components of the beam, a considerably reduced proton beam intensity could be used. For the Ξ° studies, however, an incident flux of 10^9 protons on target would be convenient. At 1000 pulses/hour, our data capability would be roughly 10^6 triggers per day.

Table II shows the expected counting rates for a 10 meter decay length using the fluxes in Table I and the detector geometry of Fig. 2. The majority of decays will be approximately equal numbers of $\Lambda^\circ \rightarrow p\pi^-$ and $K_S^\circ \rightarrow \pi^+\pi^-$. About 10% of these decays will fit either invariant mass because of the finite mass resolution of the system and the unknown beam momentum. This will present no problem for the yield measurements because the background will subtract easily from the peak, but the identification of a particular decay will be uncertain 10% of the time. This ambiguity can be resolved by the addition of a six meter long hydrogen gas cherenkov counter behind the magnet. This counter will serve to reject p's and $\bar{p}$'s with momentum below 80 GeV/c, and will aid in measuring the yields of the other less copious neutral components of the beam. The reconstruction of the Λ° events will allow a measurement of $\alpha^\Lambda \overline{P}$, and hence the Λ° polarization. To search for a non zero value of $\overline{P}$, data will be taken varying the incident proton beam angle, since it is expected that the polarization will have a very steep angular dependence. A downstream steering arrangement for the protons consisting of two main ring magnets would permit a study over a 10 mrad range.

The decay sequence $\Xi^\circ \rightarrow \Lambda^\circ\pi^\circ$, $\Lambda^\circ \rightarrow p\pi^-$ will be detected by a coincidence between a Λ° decay and a γ ray conversion from the π°. A γ counter telescope will be placed behind the apparatus for this purpose. Aside from accidental coincidences the only background for this measurement will be π° production by Λ°'s in the beam, which should be a few percent of the expected Ξ° yield. The flux of $\overline{\Lambda}^\circ$'s will be measured by using the gas cherenkov counter to veto π^- mesons, and reconstructing events assuming the charged particles to be $(\pi^+\bar{p})$. If the gas counter is 98% efficient for π^-, then the $K^\circ \rightarrow \pi^+\pi^-$ triggers will be a factor of 100 more numerous than the $\overline{\Lambda}^\circ$ triggers, but only 10% of the K°'s will reconstruct near the $\overline{\Lambda}^\circ$ mass. The anti-hyperons will then be a 10% signal on a background which is slowly varying in invariant mass. In this case a statistically significant $\overline{\Lambda}^\circ$ yield of several thousand events should be obtained in a day's run at 10^8 protons/pulse.

II. Search for $\Xi^\circ \to p\pi^-$.

Weak decays in which $\Delta S=2$ have not been observed at rates compatible with first order in the weak coupling constant G. The K_S° - K_L° mass difference is generated by a $\Delta S=2$ transition, but is consistent in magnitude with a second order weak interaction, since $\delta m \sim \Gamma_S$, which is proportional to G^2. However, terms in the weak Lagrangian which contribute to δm in first order must be even under charge conjugation, so it is possible that $\Delta S=2$ transitions with branching ratios of 10^{-3} - 10^{-4} exist which are odd under charge conjugation.[5] The observed CP violation could be one manifestation of such terms. There are not very many strange particle decays for which $\Delta S=2$ channels are available. The present experimental limits on the transitions $\Xi^- \to n\pi^-$ and $\Xi^\circ \to p\pi^-$ are each $\lesssim 10^{-3}$.[6] This experiment is designed to push the limit to $\sim 10^{-6}$.

Two modifications of the spectrometer system will be required to search for $\Xi^\circ \to p\pi^-$. The decay distance will be shortened to six meters and the magnet gap shimmed to 10" to increase the apertures because of the high transverse momentum of the decay. A ring scintillation counter will be inserted in front of the magnet to discriminate against protons from $\Lambda^\circ \to p\pi^-$ which will be closer to the neutral beam. About 12% of the $\Xi^\circ \to p\pi^-$ protons will be lost by this requirement, and 98% of the Λ° decays will be rejected. Thus about 3×10^6 triggers which will in fact be $\Lambda^\circ \to p\pi^-$ will be recorded and reconstructed in order to have "looked at" 10^6 Ξ°. This should take about 72 hours of running at 10^9 protons/pulse, and a data rate of 500 events/pulse.

III. Λ° Cross Sections in Hydrogen.

The existing data on Λp interactions have recently been compiled by the Particle Data Group.[7] The data extend up to 4 GeV/c, but are quite meager above .5 GeV/c. The total cross section in the GeV region is roughly 40 mb, half of which is elastic. The Λp system appears to have no direct channel resonances, and is similar to pp except for the absence of the one pion exchange term in elastic scattering. It seems reasonable to use the pp system as a guide in estimating Λp cross sections. Serpukhov data for pp scattering indicate a total cross section $\sigma_T = 39$ millibarn and a diffraction elastic cross section of the form $\frac{d\sigma}{dt} \propto e^{bt}$ where $b \approx (7.0 + \ln S)\,\mathrm{GeV}^{-2}$.[8] The measurement of Λ p total and diffraction elastic cross sections in the region 60 GeV - 130 GeV would clearly be of considerable interest. Data for both cross sections can be taken simultaneously.

The experimental arrangement will be identical to that for the beam survey except for the insertion of a one meter long liquid hydrogen target in the upstream part of the ten meter decay path. To detect proton recoils from diffraction scattering a range telescope will surround the target in a 2π azimuth configuration, and will be sensitive to protons with energies between about 40 MeV and 250 MeV. A 40 MeV proton corresponds to a momentum transfer $t = 2MT = .08\ (\mathrm{GeV})^2$, and a scattering angle $\theta = 3$ mrad for a 100 GeV Λ°, which will be approximately the e^{-1} point in the diffraction cross section if the parameter $b \sim 10\ (\mathrm{GeV})^{-2}$. Smaller momentum transfers will be difficult to detect by a coincidence method, so an extrapolation technique will be required to obtain $\frac{d\sigma}{dt}(t=0)$. The total cross section will be measured by a transmission method. The inherent width of the beam defined by the collimator will be 0.6 mrad fwhm with perhaps wings from collimator halo and scattering in the empty target. With the target full the diffraction scattering will contribute to the wings, as will Λ° production by the K_L° and n components of the beam. Since these effects will create Λ°'s appreciably outside of the inherent beam width, the subtraction of the "background" from the undeflected hyperon beam should be possible.

While the neutrons should present no problem through production of Λ°'s, they will create an intense charged particle background which will limit the useable flux in the neutral beam. The ratio in Table I for $n/\Lambda^\circ \sim 200$; assuming every neutron produces one charged particle in one meter of hydrogen, a maximum neutron intensity of $\sim 5 \times 10^4$ per pulse, or 200 Λ°/ pulse will be required to keep the accidentals rates manageable. If $\sigma_{tot} \sim 40$ mb, 13% of the Λ°'s will interact in one meter of hydrogen, so the statistical error in the difference measurement will be $\sim \frac{11}{\sqrt{N}}$ where N is the flux of unscattered hyperons. Thus 200 Λ°/pulse will give 2×10^6 Λ° per day, or a statistical error of a few percent in σ_{tot} in the 80 GeV to 120 GeV region where most of the detected Λ° flux will be concentrated. Increasing the Λ° production angle at the proton target from near 0 to 5 mrad or even 10 mrad will decrease the n/Λ° ratio at production, but this improvement will be lost in the 8 meter flight path through the shield because the Λ° momentum spectrum shifts to lower momenta as the production angle is increased.

The measurement of $\bar{\Lambda}^\circ p$ total cross sections may also be feasible. The use of a 10 mrad production angle for the neutral beam would be advantageous in this case, because the antiparticle momentum spectrum should not shift downward sharply compared to 0 mrad. Thus the $n/\bar{\Lambda}^\circ$ ratio should be $\sim 2 \times 10^4$ at 10 mrad, rather than 2×10^6 quoted in Table I. Using the accidentals limits quoted above, a maximum beam of a few $\bar{\Lambda}^\circ$ per pulse should be possible, requiring the order of 10^9 protons/pulse on target. Since the cross sections for $\bar{\Lambda}^\circ p$ will be larger than the $\Lambda^\circ p$ cross sections, measurements of $\sigma(\bar{\Lambda}p)$ to 10% could be obtained in the order of one week of running.

IV. Summary - Requirements for the Experiment.

The following requirments will be placed on the accelerator facilities:

1.) A proton beam near 200 GeV with a slow spill and an intensity variable between 10^8 and 10^9 protons/pulse. Steering magnets to vary the incident proton angle at the hyperon production target over the range 0-10 mrads would be advantageous. This requires two main-ring magnets.

2.) A neutral channel of approximately one microsterradian solid angle in a magnetized hadron shield 10 meters long.

3.) Floor area for the apparatus roughly 35 meters long by 3 meters wide by 3 meters high.

4.) A 1 meter cylindrical hydrogen target 2.5 cm. in diameter.

5.) Total number of beam protons interacting in the target:

a.) 6×10^{12} protons at 10^8/pulse for tuning and beam survey (3 days);

b.) 10^{13} protons at 3×10^8/pulse for the $\Xi^\circ \rightarrow p\pi^-$ search (3 days);

c.) 7×10^{12} protons at 5×10^7/pulse for the $\Lambda^\circ p$ and $\bar{\Lambda}^\circ p$ scattering measurements (1 week).

The following apparatus will be furnished by the experimenters:

1.) Chambers, counters and associated electronics.

2.) High speed buffer storage register.

3.) Spectrometer magnet with a gap approximately 30" wide and 8" high, BL = 1800 kg. - inches, to be borrowed or built on a cost shared basis. The total cost should be about $80,000.

4.) On line computer in the ASI 60-40 class (24 bit words, 32k memory). The computer facility will be shared with the negative hyperon experiment.

TABLE I

Neutral particle fluxes estimated using Walker's[2] yield curves. A solid angle of 10^{-6} sterad at 0 mrad and a flight path of 8 meters were assumed. All fluxes are per 10^{10} interacting protons.

Particle	Flux	Most Probable Momentum	
n	10^8	180	Slowly varying momentum Spectrum 100-200 GeV/c
$\bar{n}$	10^5	40	Anti-particle momentum Spectrum falls off sharply with increasing momentum
Λ°	5×10^5	120	
$\bar{\Lambda}^\circ$	50 ?[a]	40	
Ξ°	5×10^3 ?[b]	120?	Same momentum spectrum Assumed for Ξ° and Λ°
$\bar{\Xi}^\circ$	.5	40	
K_L	1.35×10^6	60	Vacuum interference Significant at $\sim$20 GeV/c
K_S	$.15 \times 10^6$	80	

a) Antiparticle/particle ratio assumed to be 10^{-3}. The extra factor of .1 comes from the decay of the $\bar{\Lambda}^\circ$'s which have an average momentum 1/3 that of the Λ°'s.

b) The Ξ flux is rather arbitrarily taken to be 1% of the Λ° flux.

TABLE II

Neutral particles detected in a 10 meter decay length. These numbers were obtained from the fluxes and momentum spectra in Table I, combined with the appropriate lifetimes, branching ratios, and detection efficiencies. All yields are for 10^{10} interacting protons.

PARTICLE	FLUX 8M FROM TGT	YIELD FROM 8 to 18 M
Λ°	5×10^5	2.6×10^5
$\bar{\Lambda}^\circ$	50	26
Ξ°	5×10^3	1.3×10^3 [a]
$\bar{\Xi}^\circ$	.5	.1
K_S	1.5×10^5	1.0×10^5
K_L	1.35×10^6	2×10^3 [b]

a.) For illustration, the efficiency of .26 for Ξ° comes from .33 for the chain $\Xi^\circ \rightarrow \Lambda^\circ \rightarrow p\pi^-$ to be detected in 10 meters, and .8 for detecting a π° γ ray behind the apparatus.

b.) This number includes leptonics and τ's which count but do not have unique invariant mass. For $K_L^\circ \rightarrow \pi^+\pi^-$, the expected yield is $\sim$10.

FIGURE CAPTIONS

1.) Possible shield and collimator configuration for the short lived beams. The letters refer to the following: A) incident proton beam in the intensity range $10^8 - 10^9$ with variable angle of incidence over 0 - 10 mrad; B) one interaction length Cu target; C) heavymet or other high density shield near the target with a channel in the forward direction; D) one microsterad channel in the iron shield, 8 meters long; and E) magnetized iron shield. The heavymet high density shield is solid for about 1/2 interaction length in the direction of the neutral beam to eliminate the γ ray component.

2.) Proposed experimental arrangement for the beam survey. A vacuum pipe will be placed along the 10 meter decay length during the survey to minimize gas interactions. P1, P2, P3 are proportional counters of the Charpak type. M is the analyzing magnet. S1, S2, S3 are magnetostrictive readout wire chambers. C is a 6 meter long hydrogen gas Cherevkov counter split into two separate compartments for positively and negatively charged particles. H1 and H2 are scintillation counter hodoscopes, and H3 is a lead and lucite hodoscope for γ ray conversion. For the cross section studies a 1 meter long liquid hydrogen target will be inserted at LH_2.

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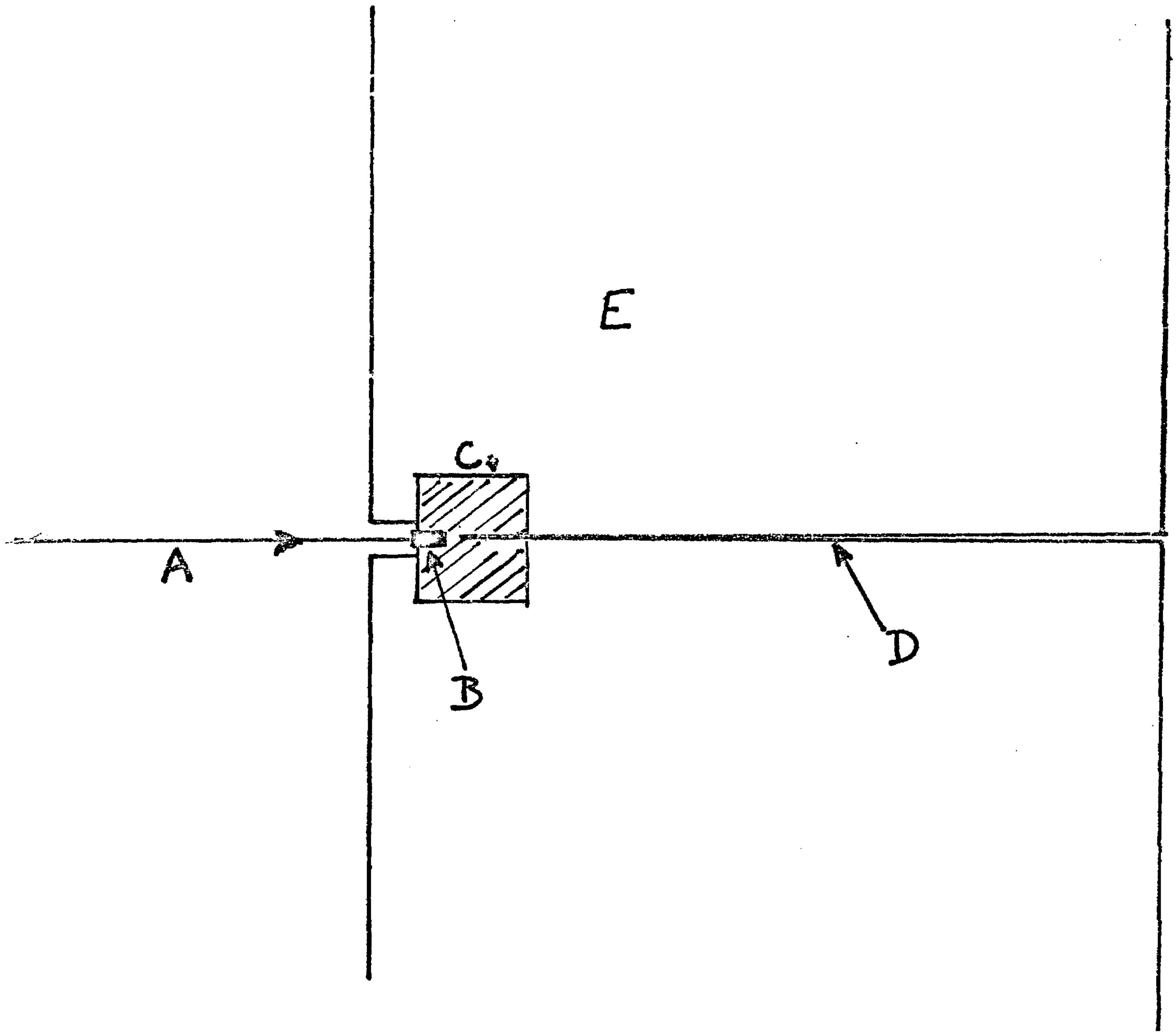

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FIG 1

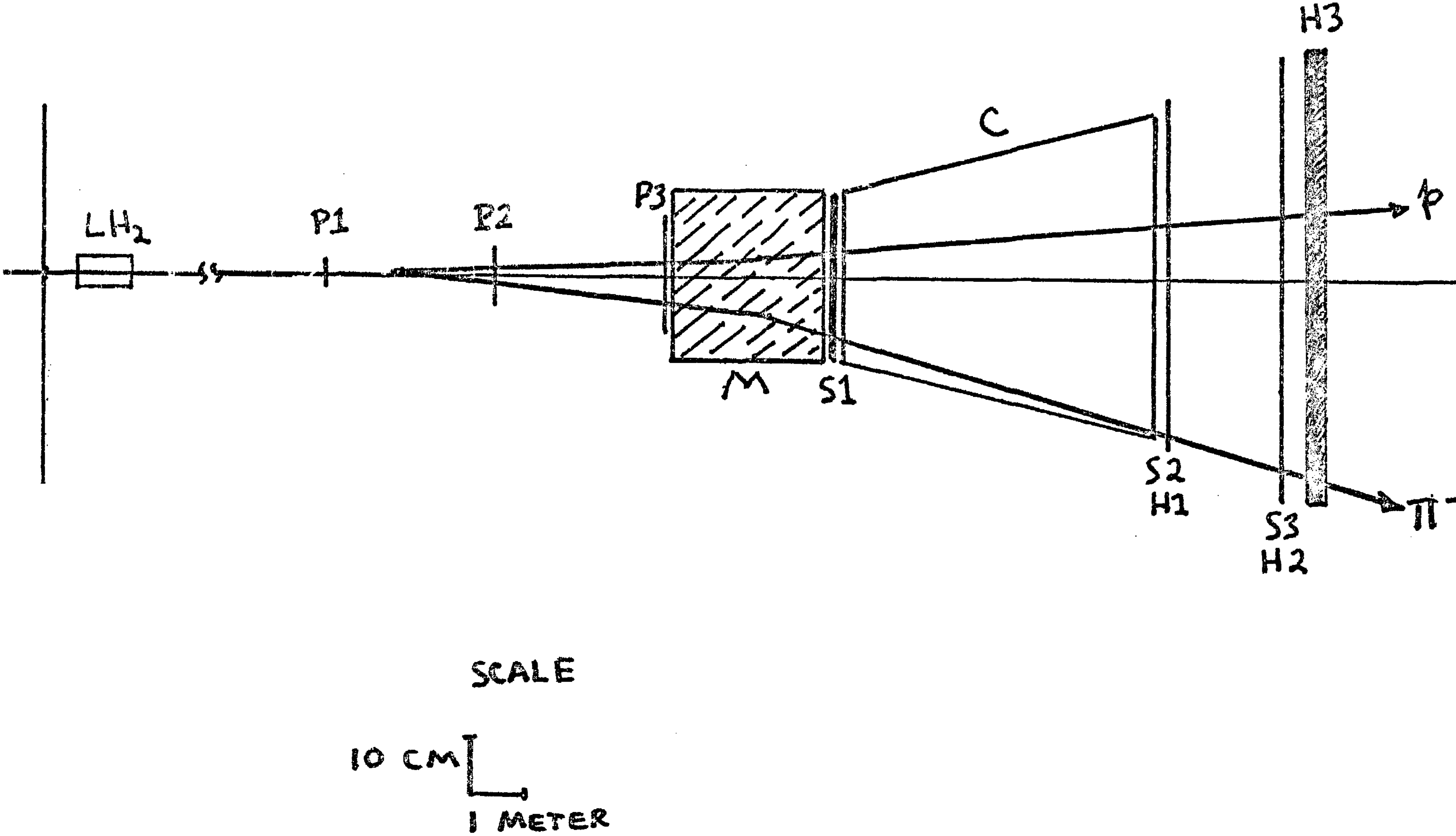

FIG. 2